Groundwater Gradient Evaluation for the Red Hill Bulk Fuel Storage Facility

Prior to the installation of the monitoring well network at the Red Hill Bulk Fuel Storage Facility (RHBFSF), the observation well locations in the Honolulu Aquifer did not provide a geometry that could adequately evaluate the assumed "mauka to makai" (i.e. mountain to sea) groundwater flow gradient. The monitoring wells at the RHBFSF are aligned mauka to makai providing a unique opportunity evaluate the groundwater gradient in this direction. A wealth of water level has been collected by the monthly Oil/Water Interface measurements done on the wells inside of the RHBSF lower tunnel.

Methodology

Measured water level elevations were taken from the monthly Oil/Water Interface Reports. These elevations were plotted going mauka to makai (i.e. in the topographically down gradient direction). The measured water table elevations were compared to those estimated by three different groundwater modeling studies. The gradient in ft/mi were estimated from figures of the simulated water table elevation. The modeled water levels in the downslope wells were calculated by assigning the measured water level to the most mauka well then computing the water levels in the makai wells using the groundwater gradient estimated by each of the modeling studies. The studies used were:

- Oki, 1997
  - Oki, D.S. 1997. Geohydrology of the Central Oahu, Hawaii, Ground-Water Flow System and Numerical Simulations of the Effects of Additional Pumping. USGS Water-Resources Investigations Report 97-4275
- Todd Engineers, 2005
  - Todd Engineers, 2005. Development of a Groundwater Management Model - Honolulu Area of the Southern Oahu Groundwater System. Prepared by Todd Engineers for the Honolulu Board of Water Supply. October 2005
- Rotzoll and El-Kadi, 2007
  - Rotzoll, K., and A.I. El-Kadi. 2007. Numerical Ground-Water Flow Simulation For Red Hill Fuel Storage Facillities, NAVFAC Pacific, Oahu, Hawaii. Prepared by University of Hawaii, Water Resources Research Center for the Navy Facilities Command, Hawaii. August 2007

As part of the USGS/HBWS pump test, regional water levels were recorded for much of April and May, 2015. On May 28, 2015, at the end of the record for this pumping test, a round of oil water interface measurements were taken. This data allows the mauka to makai groundwater gradient for the entire facility to be evaluated.

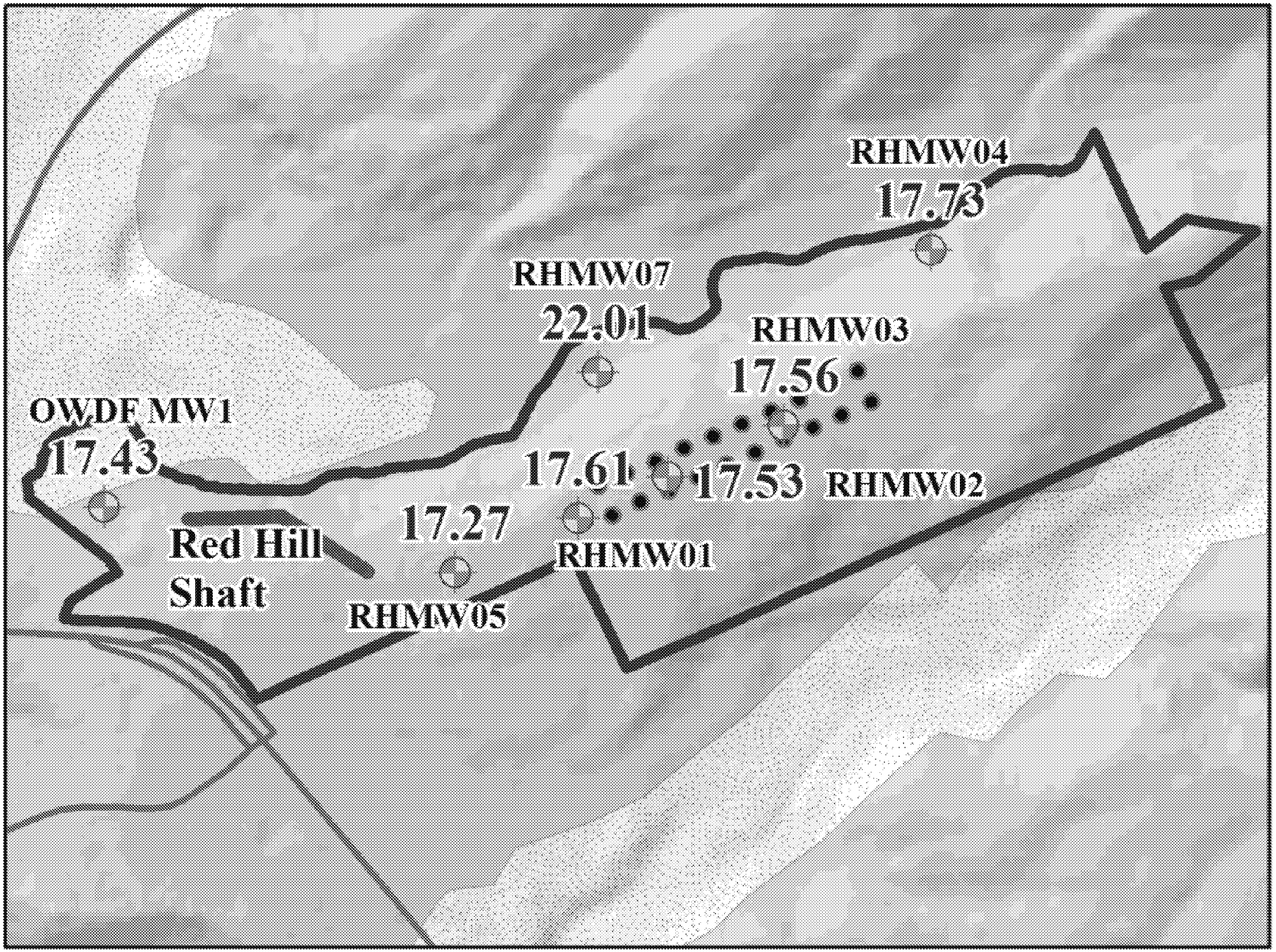

Figure 1. A map of the RHBFSF showing the location of the monitoring wells and the water elevations measured on or about May 28, 2015. With the exception of RHMW07, a well with a anomalously high water level, the groundwater gradient if relatively flat until the mauka to makai transect reaches RHMW05.

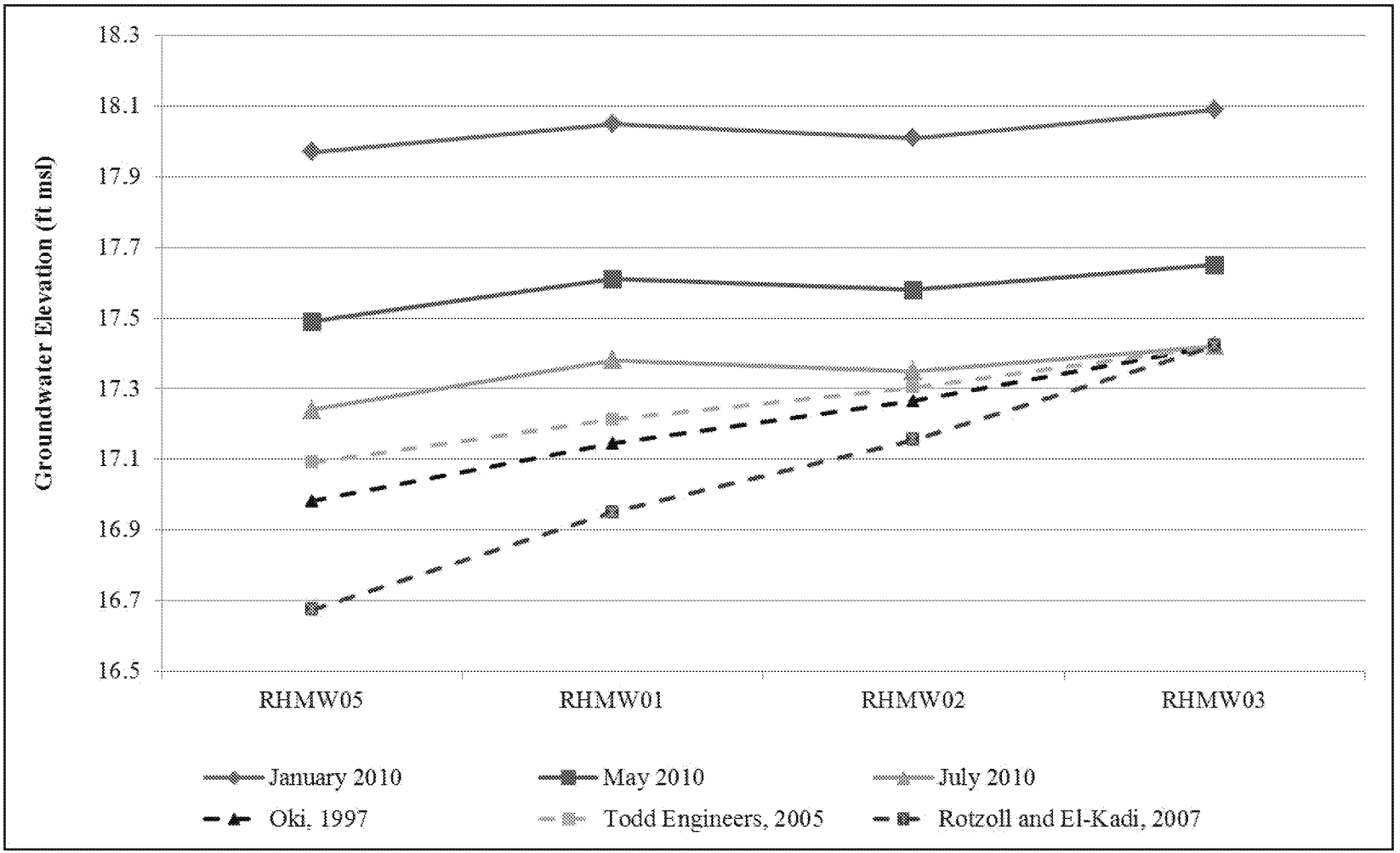

Figure 2. A graph of the water levels measured in the tunnel wells by TEC, the Navy's contractor in 2010. The Navy's technical representative, Paul Eyre, had imposed a requirement on TEC that the Red Hill Shaft had to be shut off for at least 16 hours prior to a round of water level measurements. This provides a water level history water levels with no local pumping occurring. The measured data indicated by the solid lines show a very weak mauka to makai gradient. The water levels calculated using gradients estimated by three different groundwater modeling studies shows a much stronger mauka to makai gradient should be expected.

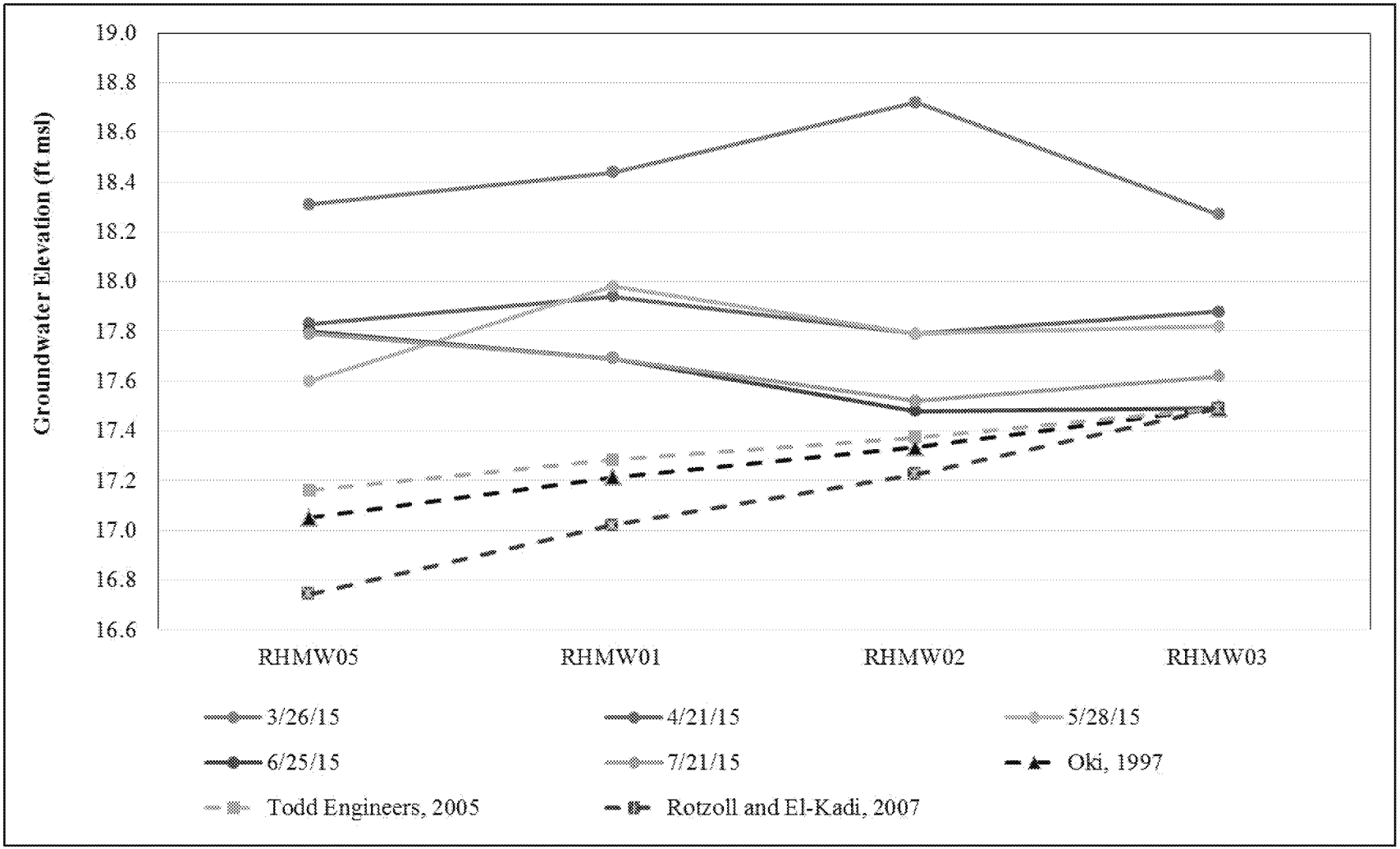

Figure 3. A graph of the water levels measured in the tunnel wells by ESI, the Navy's current contractor. The measured data indicated by the solid lines show a virtually no mauka to makai gradient. The water levels calculated using gradients estimated by three different groundwater modeling studies shows a strong mauka to makai gradient should be expected.

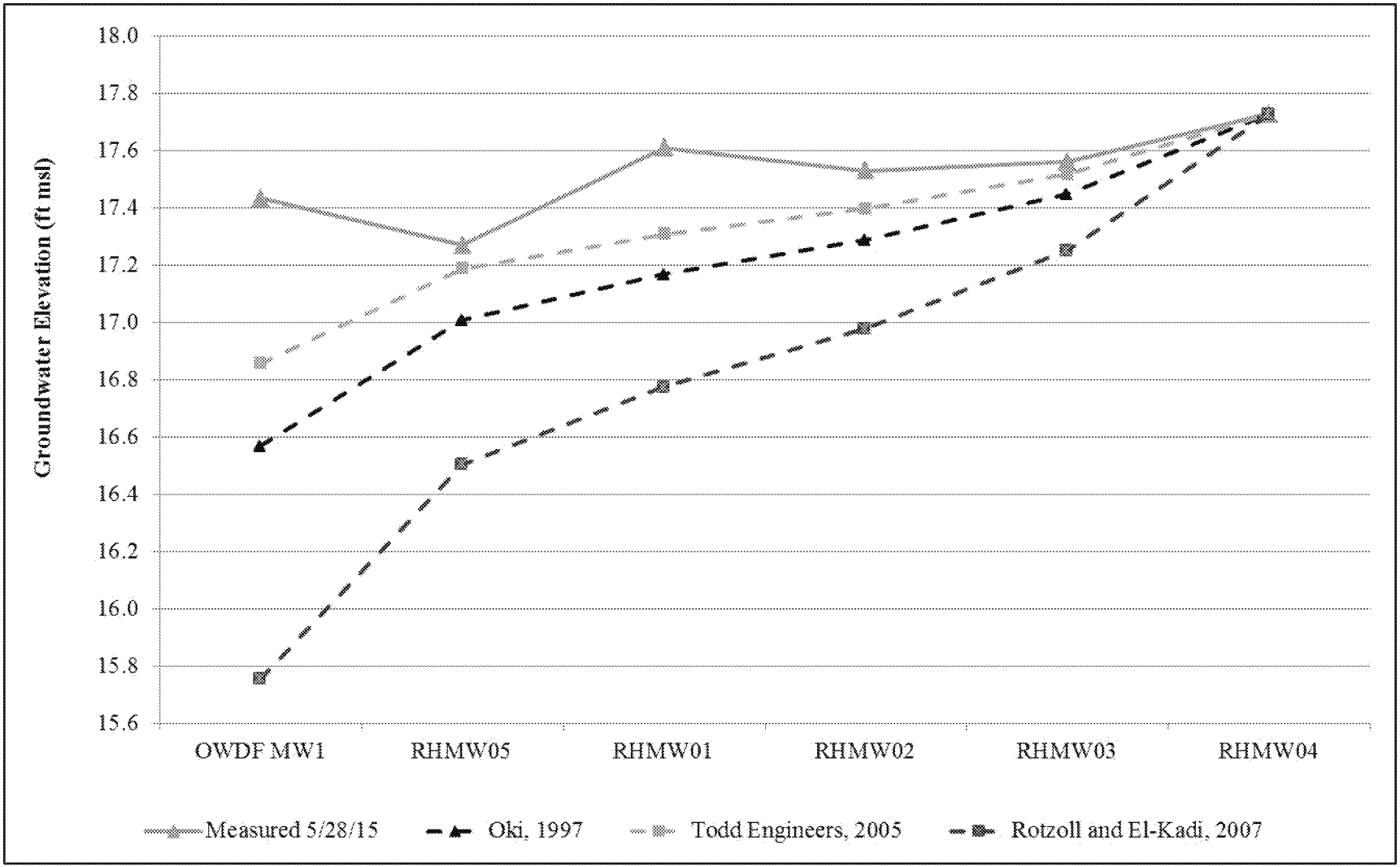

Figure 4. A graph of the water levels measured in the tunnel wells by ESI, and by the USGS and HBWS during the April/May, 2015 pumping test. The measured data, indicated by the solid lines, shows weak mauka to makai gradient from RHMW04 to OWDF-MW1, but virtually no gradient from RHMW03 to RHMW01. There is a measured gradient from RHMW01 to OWDF MW1 as would be expected since the Red Hill Shaft was pumping normally. Again, expected water levels were calculated using gradients estimated by three different groundwater modeling studies. The calculated water levels shows a much stronger mauka to makai gradient should be expected.

The pump test record ended about 08:00a on 5/27/15 for OWDF MW-1 and RHMW04 the water table elevation displayed are the average from 08:00a 5/26/15 to 08:00a 5/27/15.

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Conclusions

In all cases the measured mauka to makai groundwater was significantly less than predicted by each of the groundwater models. The water levels calculated based on the modeled gradient are what would be expected if the simulated flux of groundwater was flowing mauka to makai. The comparison between the measured and modeled water levels shows a measured gradient that is much less than that consistent with modeled mauka to makai groundwater flow. The relationship between groundwater flow and groundwater gradient is described by Darcy's Law:

$q = K*grad(h)$

Where:

q = groundwater flow (ft3/ft2/d)
K = hydraulic conductivity (ft/d)
grad(h) = hydraulic gradient (ft/ft)

Transposing Darcy's Law to solve for hydraulic gradient:

$grad(h) = q/K$

infers that either the modeled hydraulic conductivity is too low or the modeled groundwater flow in the mauka to makai direction is to too high. Much of the measured hydraulic gradient (i.e. from RHMW03 or 04 to RHMW01 is nearly flat inferring very little groundwater flow. The assumption that the dominant groundwater flow being in the mauka to makai direction needs to be seriously re-evaluated. However, this is not the final work since geochemistry data indicates (and is logical since water has to flow to the Red Hill Shaft to replace that pumped) flow from RHMW02 toward the Red Hill Shaft. At the same time, geochemistry also infers some component of groundwater from beneath the tanks to RHMW04. Hydrogeologically, this is a very complex site with no easy answers (refer to map on 2nd page for monitoring well locations).